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**NEW APPROACHES TO RECONFIGURABLE  
OPTICAL INTERCONNECTS**

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The objective of this effort is to define and evaluate new approaches to two-dimensional arrays of reconfigurable optical interconnections and arrays of optical neurons for optical computing. The emphasis is on optically-controlled optical beam directors or switches and optically-saturated neurons which can be fabricated into high density 2-D arrays. Using field shielding and optically-controlled electric field patterns in CdTe, controlled switching in the IR, infrared neurons with a variety of properties and optically-controlled beam deflection have been demonstrated. A study of organic nonlinear materials for potential use in charge transfer assisted optical switching devices is included.

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## INTRODUCTION

This report covers the period from Oct. 1, 1987 through Sept. 30, 1990, the three year period of the contract AFOSR -87-0338. The objective of this effort is to define and evaluate new approaches to two dimensional arrays of reconfigurable optical interconnections for optical computing. The emphasis is on optically controlled optical beam directors or switches which can be fabricated into high density 2-D arrays. The proposed applications in optical neural computers and other types of optical computers require reconfiguration speeds on the order of microseconds. The emphasis is therefore on devices and nonlinear optical materials with response times of microseconds but with the potential for high packing density.

The approach to this research has two components:

- i. nonlinear optical materials
- ii. optically controlled optical switching devices which can be integrated into 2-D arrays.

The materials work stresses the transport assisted optical nonlinear materials since this is the only class of materials which exhibit a sufficiently large nonlinearity, in the response time required, and with a relatively low optical energy required. In these materials, optically excited electric charge is separated by an electric field to create a space charge field which reduces the total electric field. The change in the field effects the optical properties of the material by effects such as the electrooptic effect or the Franz-Keldysh effect. In many cases this is a broad band effect which can be used in the infrared where diode laser sources exist.

A figure of merit can be defined,  $n^3r/\epsilon$ , where  $r$  is the electrooptic coefficient and  $\epsilon$  is the relative dielectric constant, which gives a relative measure of the change in the index of refraction per photon absorbed. We are working with two of the materials with the highest figures of merit and therefore with the maximum potential: CdTe ( $n^3r/\epsilon = 16.0$  pm/V) and organic molecules ( $n^3r/\epsilon = 58$  pm/V for DPR-19 polymer).

Our work on field shielding in CdTe is the first demonstration of a transport assisted approach which makes full use of the potential of CdTe. We have demonstrated optically controlled switching, infrared neurons, and infrared limiting in the IR using this effect and have demonstrated a 1-D array with 4 lines/mm resolution.

The organic materials offer an enormous amount of diversity and therefore have an enormous potential in the field of nonlinear optics. However to date there has been a relatively small number of applications of these materials. We have initiated a materials study under this

program with the goal of using the transport assisted concept with organic materials.

We have studied, in conjunction with chemists at Penn State University and the Northern Illinois University, a new class of polymers, organophosphazene, with second order nonlinear side chains attached. The second order nonlinearity of this class of polymers shows promise as a new approach. In addition we have measured a class of dye-like aromatic molecules using second harmonic generation techniques by doping the molecules into polymer hosts and using corona poling.

Our most promising results for a material with potential for immediate application in optical switching and modulation is the disperse red dyes covalently side chain bonded to polyester polymers. These materials show a stable electrooptic effect comparable to  $\text{LiNbO}_3$  and can be patterned into waveguide structures by UV exposure.

### RESEARCH PROGRESS

The details of the research progress are well documented in the publications resulting from this work which are listed in a later section and referenced here. This report will therefore only summarize and give the highlights of the results. The reader is referred to the publications for more details.

#### OPTICAL SWITCHING, POWER LIMITING, AND OPTICAL NEURONS IN CDTE

The field shielding effect in CdTe has been used to demonstrate optically controlled optical switching in the infrared. In this large nonlinear effect, a control beam creates electric charge which drifts in the applied electric field and shields the illuminated region from the applied field. This optically controlled change in the electric field is then used to control the polarization of the signal beam. The signal beam can be of low intensity at the same wavelength as the control beam, can be of high intensity but at a longer wavelength than the control beam, and can be either co-linear or perpendicular to the control beam. The details of this work are given in Publications 4 and 5 and can be summarized as follows:

1. Minimum control beam intensity for switching -  $1.0 \text{ mW/cm}^2$
2. Switching speed -  $1.0 \text{ } \mu\text{sec}$  at  $10 \text{ W/cm}^2$
3. Useable wavelength range -  $0.9$  to  $1.4 \text{ } \mu\text{m}$ .

In addition we have demonstrated power limiting and self switching at  $1.06 \mu\text{m}$  using a colinear geometry. The effect has a relatively low



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threshold of  $100 \mu\text{W}/\text{cm}^2$  and extrapolated switching time of microseconds. The details are given in Publication 3.

A novel infrared neuron that utilizes the field shielding effect in CdTe:In has been demonstrated in several forms and described in Publications 6, 7, and 8. This neuron, which is shown schematically in Figure -- has potential applications in neural net optical computers. The device has a high sensitivity nonlinear saturating response with an absorption loss of less than 1.0 dB. Operation with synchronous microsecond pulses and with both excitatory and inhibitory inputs have been achieved. Additional interesting features include the possibility of a broadband (0.9-1.4 $\mu\text{m}$ ) response to incoherent inputs and a configuration for a bidirectional neuron which can be used in backpropagating error learning networks.

In more recent work we have observed a very large optically created and optically erased build up of the electric field under the negative electrode in biased CdTe samples. The optical control of the magnitude and the position of this field build-up, typically 10-20 times the applied field, combined with the electrooptic or the Franz-Keldysh effect, provides a novel large optical nonlinearity. The high field region (0.1-0.2mm wide) forms in a few microseconds upon illumination by below bandgap light (860-900nm) and persists in the dark with a latch time of 2-5 seconds. This effect is highly sensitive, requiring approximately  $10\text{nJ}/\text{cm}^2$  absorbed fluence, and exhibits an intensity and applied voltage dependent response time. Furthermore, this high field can be erased by illuminating the region through ITO electrodes with near bandgap light (835nm GaAs laser diode). This field buildup and erasure can be used in a variety of device configurations (1 or 2 dimensional arrays, self switching or two wavelength schemes) for opto-optical switching and spatial light modulation applications. A 1-D array using the electrooptic effect is shown in Figure--; the device has the following properties:

1. Switching time - 1  $\mu\text{sec}$ .
2. Latching time - 2-5 sec.
3. Resolution in a 1-D array - 4 lines/mm.
4. Switching energy per channel - 50 pJ.

We have also considered a 2-D array configuration using the electro-absorption effect (Franz-Keldysh) and made measurements of the effect in CdTe and observed self switching and two-wavelength switching.

Please refer to Publications 9 and 17 for details.

#### **SECOND ORDER ORGANIC MATERIALS AND DEVICES**

We have synthesized and measured the second order nonlinear optical properties of a promising new class of polymers. The polyphosphazene polymer in which a nitrostilbene unit is covalently linked

to the polymer chain through a tris(ethylene oxide) spacer group has been studied and reported on in Publication 12. This class of polymers has the advantage in that the macroscopic properties can be tailored by the incorporation of specific substituent groups. Using corona poling and second harmonic generation to characterize the nonlinear effects we have shown the potential of this class of polymers

A photophysical and structural study of several dye-type compounds containing various donor-acceptor groups and heteroatoms has been completed and reported on in Publications 10, 11, and 13. The three-ring systems examined exhibited high  $\mu\beta_0$  values, comparable to or better than MNA, but with improved thermal and photochemical stability. The growth of these molecules into organic crystals was explored with an X-ray diffraction structure analysis.

Our most promising results have concerned polyesters containing disperse red dye as pendant side chains. These polymers are soluble in many organic solvents and can be processed into thin films by spin-coating. It was found that these polymers exhibit large and stable second order electrooptic effects characterized by second harmonic generation. With the corona poling method, large resonance enhanced second order nonlinear coefficients,  $\chi^{(2)}$ , of 590 pm/V for polymer 1 and 280 pm/V for polymer 2 were observed at 532 nm. When these values are extrapolated to 800 nm, the transparent region for these polymers,  $\chi^{(2)}$  values of 112 pm/V and 84 pm/V were obtained for the two polymers respectively. It has been demonstrated that these  $\chi^{(2)}$  values are stable at 80% of their maximum values for more than 1000 hrs.

The photoinduced refractive index change of polyester with disperse red side groups as studied at several different wavelengths. An index change of 0.3 at 633 nm, the largest ever reported among second-order nonlinear optical polymeric materials, was observed in this polymer system. This index change was monitored over 1000 hrs. and long term stability was demonstrated. Based on these results, a method using only photomasks to define channel waveguides and other patterns in such polymers was suggested and experimentally demonstrated. This photoinduced index change may have wide applications in integrated optical systems when these or similar polymers are involved.

The results on the polyester with disperse red are reported in Publications 15, 16, and 18. Figures 3 and 4 show the structure and list the properties of these materials.

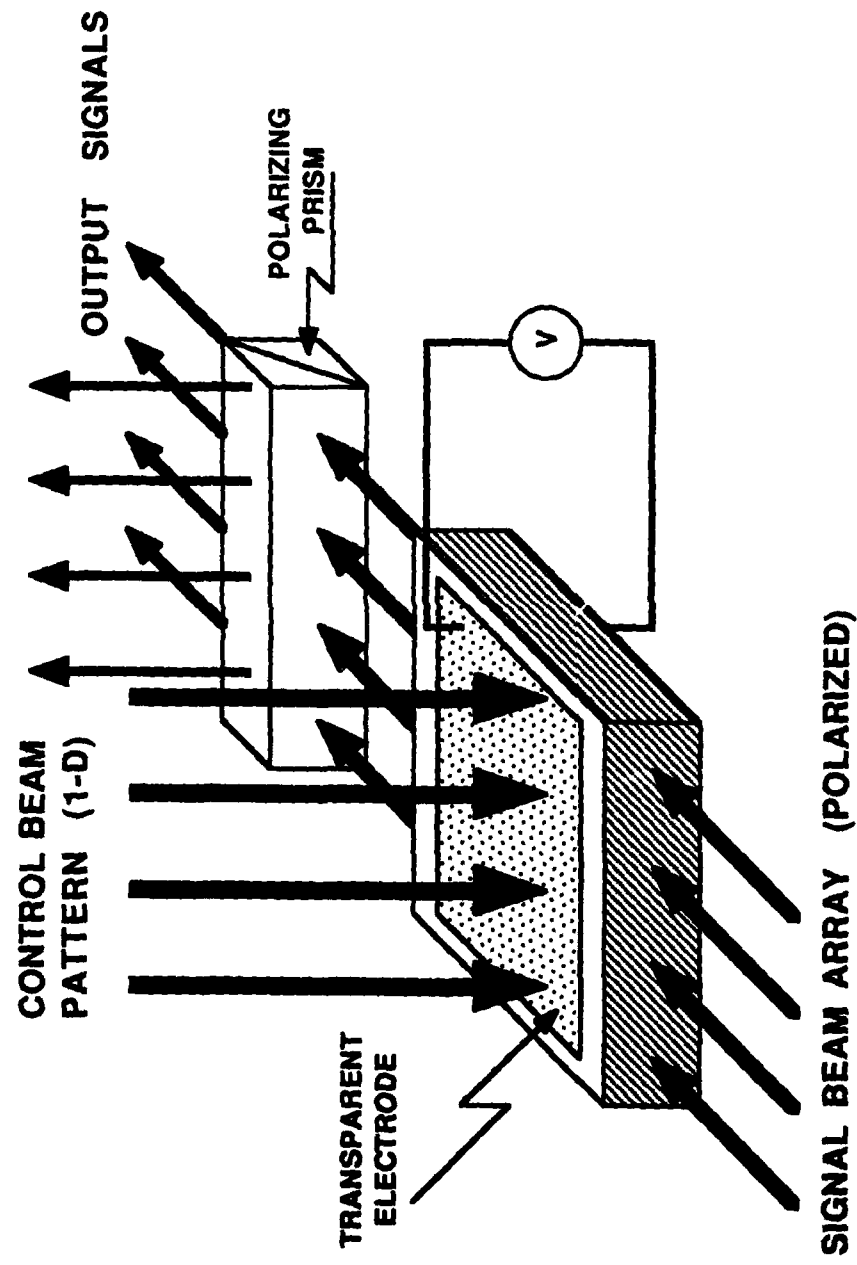


Fig. 1) A one-dimensional opto-optical switching array consisting of a transparent ITO electrode deposited on a CdTe electrooptic crystal.

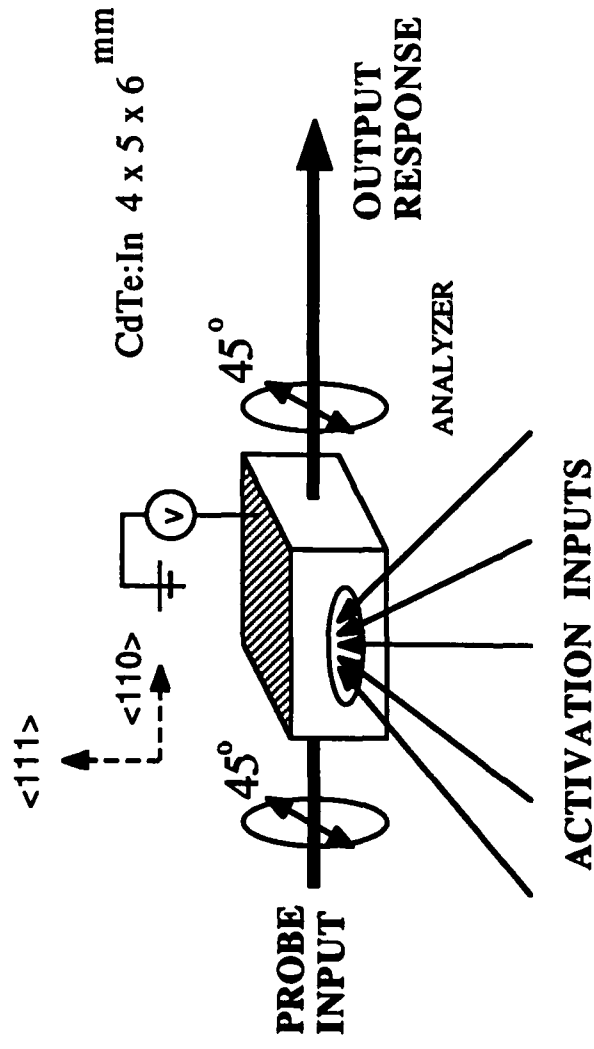
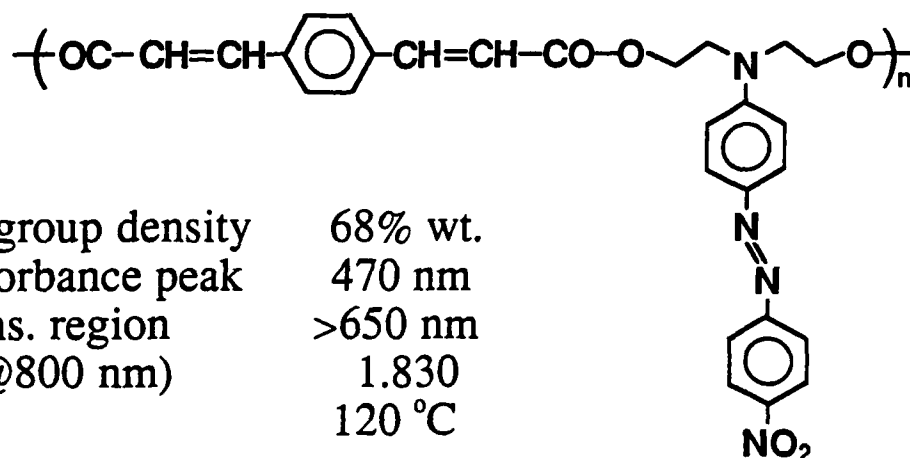


Fig 2 ) A CdTe based neuron where a low intensity polarized probe input is incident on the crystal. The activation inputs are applied to the crystal and alter the local electric field which is sensed by the probe beam.

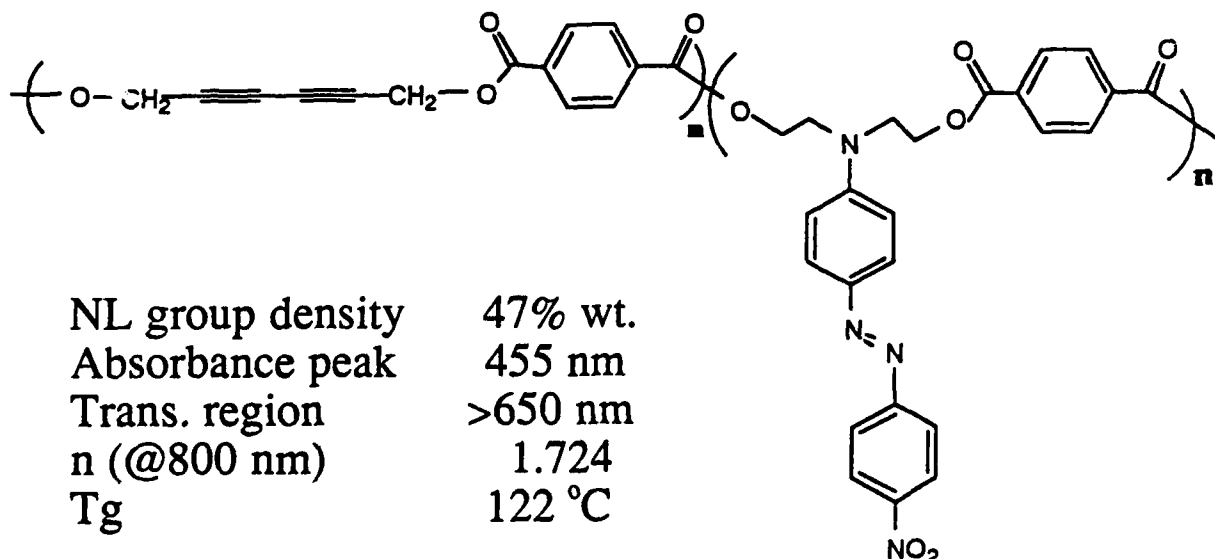
## Polymer Structures and Physical Properties

### Polyester with disperse red 19 side group (PE-DR19)



NL group density	68% wt.
Absorbance peak	470 nm
Trans. region	>650 nm
n (@800 nm)	1.830
T <sub>g</sub>	120 °C

### Copolyester with disperse red 19 side group (CoPE-DR19)



NL group density	47% wt.
Absorbance peak	455 nm
Trans. region	>650 nm
n (@800 nm)	1.724
T <sub>g</sub>	122 °C

FIGURE 3

## Experiment results

At 1.064  $\mu\text{m}$  fundamental wavelength, using crystal quartz as reference and taking  $d_q = 0.5 \text{ pm/v}$

$$\text{PE-DR19:} \quad d_{33} = 295 \text{ pm/v} \quad \chi^{(2)}_{33} = 590 \text{ pm/v}$$

$$\text{CoPE-DR19:} \quad d_{33} = 140 \text{ pm/v} \quad \chi^{(2)}_{33} = 280 \text{ pm/v}$$

Using a two level model to extrapolate these resonance enhanced values to 800 nm

$$\text{PE-DR19:} \quad d_{33} = 56 \text{ pm/v} \quad \chi^{(2)}_{33} = 112 \text{ pm/v}$$

$$\text{CoPE-DR19:} \quad d_{33} = 42 \text{ pm/v} \quad \chi^{(2)}_{33} = 84 \text{ pm/v}$$

The corresponding electro-optic coefficient of electronic origin at 800 nm

$$\text{PE-DR19:} \quad r_{33} = 26 \text{ pm/v}$$

$$\text{CoPE-DR19:} \quad r_{33} = 24 \text{ pm/v}$$

Fig. 4

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